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Injury to the Growth Plate After Pemberton Osteotomy*

BY ARABELLA I. LEET, M.D.†, WILLIAM G. MACKENZIE, M.D.‡, GEORGE SZOKE, M.D.§, AND H. THEODORE HARCKE, M.D.‡, WILMINGTON, DELAWARE

Investigation performed at the Alfred I. duPont Hospital for Children, Wilmington

ABSTRACT: The Pemberton osteotomy involves cutting directly into the iliopubic and ilioischial limbs of the triradiate cartilage of the acetabulum. Complete closure of the triradiate cartilage after this osteotomy has been described in case reports. The present experimental study was performed to determine whether physeal osseous bars formed after Pemberton osteotomy.

Eight Pemberton osteotomies were performed in six piglets. The animals were killed, and the acetabula were studied with use of radiography, computed tomography, and histological analysis for evidence of physeal injury.

Plain anteroposterior radiographs of the pelvis did not clearly demonstrate the formation of osseous bars. However, Bucholz radiographs, made with the acetabulum placed directly on the cassette, showed osseous bars in three of the four specimens that were studied in this manner. Histological sections of the eight specimens of triradiate cartilage demonstrated five osseous bars in the iliopubic limb and four in the ilioischial limb. In two specimens, there was disruption of the cartilage without osseous bridging. Only two of the eight specimens had normal histological findings in both the iliopubic and the ilioischial limb of the triradiate cartilage.

CLINICAL RELEVANCE: The results of the present study demonstrate that crossing the triradiate cartilage with an osteotome can cause the formation of an osseous bar in the triradiate cartilage. Such a bar may cause growth arrest and could lead to acetabular dysplasia secondary to disturbance of normal pelvic growth.

In growing children, premature complete closure of the triradiate cartilage causes thickening of the medial aspect of the acetabular wall and a shallow acetabulum. As the femoral head continues to grow, the shallow acetabulum may fail to contain it. The result is progressive uncovering of the femoral head[2,5,6,9]. Premature closure of the triradiate growth plate has been reported as a sequela of trauma[1], neonatal sepsis[2], and acetabuloplasty[9]. Recently, Steel described intentional closure of the triradiate cartilage to treat protrusio acetabuli[14]. Regardless of the etiology, the acetabulum cannot form normally after closure of the triradiate cartilage. The severity of the resulting acetabular dysplasia depends on the age of the patient at the time of premature closure of the physis and the degree of damage to the physis.

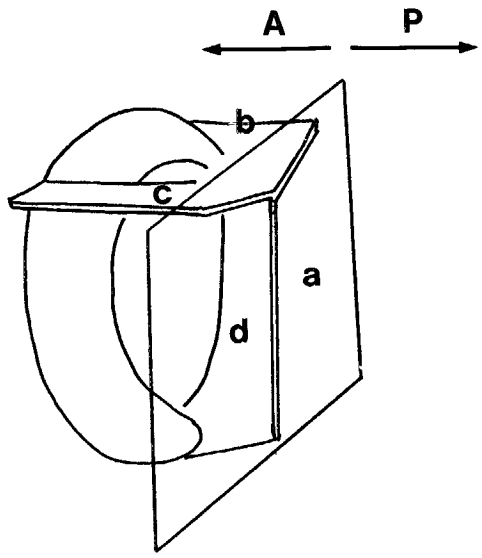

FIG. 1

Diagram of the triradiate cartilage, showing the shape of the acetabular growth plate and the orientation of the histological sections. a = plane of the histological sections, b = ilioischial limb, c = iliopubic limb, d = ischiopubic limb, A = anterior, and P = posterior.

Pemberton described an osteotomy that involves a cut extending to the iliopubic and ilioischial limbs of the triradiate cartilage to correct acetabular dysplasia[7,8]. The superior acetabular fragment is hinged through the triradiate cartilage and brought over the femoral head, thereby providing increased acetabular coverage. Pemberton maintained that inadvertent penetration of the triradiate cartilage with an osteotome had no adverse effects[7,8]. However, other authors, such as McKay, suggested that a Pemberton osteotomy be performed with caution, as an osseous bar was noted to have formed

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†Orthopaedic Hospital, 2400 South Flower Street, Los Angeles, California 90007.

‡Departments of Orthopaedics (W. G. M.) and Medical Imaging (H. T. H.), Alfred I. duPont Hospital for Children, 1600 Rockland Road, P.O. Box 269, Wilmington, Delaware 19899. E-mail address for Dr. Mackenzie: wmackenz@aidi.org. Please address requests for reprints to Dr. Mackenzie.

§Department of Orthopaedics, Semmelweis University, Karvlina u.27, Budapest H-1113, Hungary.

FIG. 2

Anteroposterior radiograph of a left hip, made immediately after a Pemberton osteotomy.

across the triradiate cartilage in some patients and damage to the triradiate cartilage was a possible serious complication[6].

The effects of injury of the triradiate cartilage as a sequela of pelvic trauma have been studied in children. Bucholz et al., in a study of pelvic fractures in children, reported that Salter-Harris type-I, II, and V fractures occur through the triradiate cartilage[1]. Although type-I and II fractures involving shear forces across the acetabulum do not seem to arrest the growth of the triradiate cartilage, type-V fractures that involve crushing of the triradiate cartilage are associated with closure of the triradiate cartilage. In addition, Bucholz et al. observed that closure of the triradiate cartilage occurred only in children who were less than ten years old. After the age of ten years, the triradiate cartilage no longer seems susceptible to injury, although complete closure of the triradiate cartilage may not occur until the age of fifteen to eighteen years[10].

Studies of animals have shown that complete closure of the triradiate cartilage disrupts the growth of the acetabulum. By closing the triradiate physis in rabbits, Gepstein et al. reproduced the constellation of radiographic changes — that is, a shallow acetabulum and subluxation of the femoral head — seen in children after traumatic closure of the triradiate cartilage[3]. Greater derangement of the hip joint occurred in younger rabbits[3,5].

Additional work with the rabbit model demonstrated the particular sensitivity of the various limbs of the triradiate growth plate to damage and the effect of such damage on the future development of the ace-

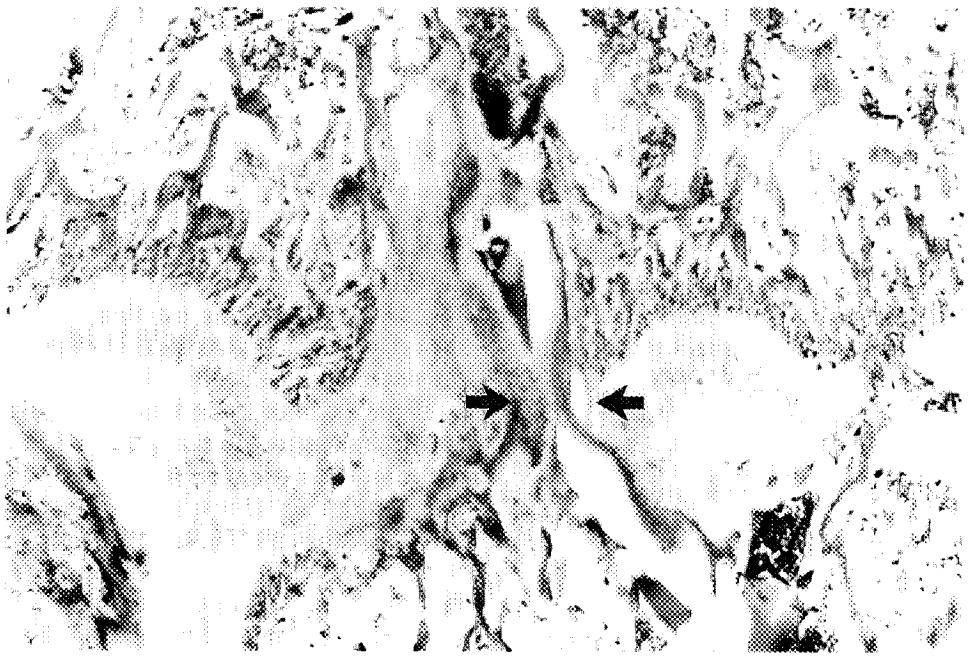

FIG. 3

Photomicrograph demonstrating an osseous bar with disruption (arrows) of the adjacent triradiate cartilage in the ilioischial limb two weeks after a Pemberton osteotomy (hematoxylin and eosin, × 2.5).

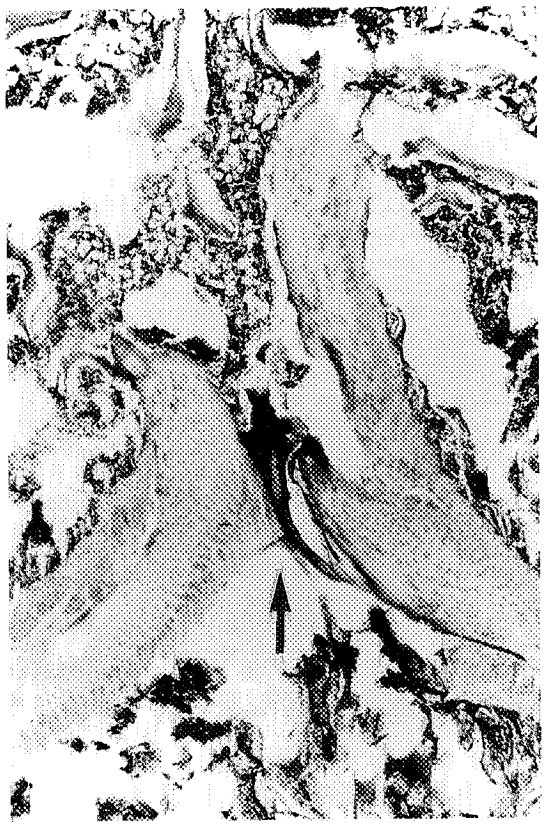

FIG. 4

Photomicrograph showing disruption of the ilioischial limb of the triradiate cartilage (arrow) two weeks after a Pemberton osteotomy (hematoxylin and eosin, × 2.5).

tabulum[3]. Experimental closure of the iliopubic limb in rabbits had little effect on acetabular development. However, closure of the ilioischial limb produced a disruption in growth that was identical to that seen when the entire triradiate growth plate was closed.

We questioned whether closure of the triradiate cartilage might be a result of the underlying disease rather than a sequela of injury to the triradiate cartilage during a Pemberton osteotomy. The triradiate cartilage is a complex structure; two of its limbs are superimposed on routine anteroposterior radiographs. Therefore, radiographic analysis of the formation of osseous bars in the triradiate cartilage after a Pemberton osteotomy might not be reliable. The extent of damage to the triradiate growth plate is discernible only in a study of an animal model.

Materials and Methods

A pregnant, domestic, Yorkshire-Landrace sow that was near term was obtained to furnish a healthy litter for this study. After it gave birth, adhesive tape was placed circumferentially proximal and distal to the knee joints of six newborn piglets to maintain the hips in a position of adduction and extension in order to promote acetabular dysplasia[4,11-13]. Another piglet served as a control. (The limbs of this piglet were not taped, and the animal did not have hip dysplasia. The triradiate cartilage was examined histologically and was normal.) The tape was changed at least twice a week to allow for growth; otherwise, it was not removed. The animals were able to move freely about the pen, which they did easily by hopping, despite the lower-extremity restraints. It has been shown that this simple manipulation results in acetabular dysplasia within six weeks[11-13].

At six to eight weeks of age, the piglets were sedated with ketamine and preoperative anteroposterior radiographs of the pelvis were made. A Pemberton osteotomy was then performed through an anterolateral approach. It was done unilaterally in four animals and bilaterally in two. For the operative procedure, the animals were given halothane anesthesia through an endotracheal tube. The osteotomy was performed without radiographic guidance. The operative exposure enabled clear visualization of the pelvic anatomy over the trira-

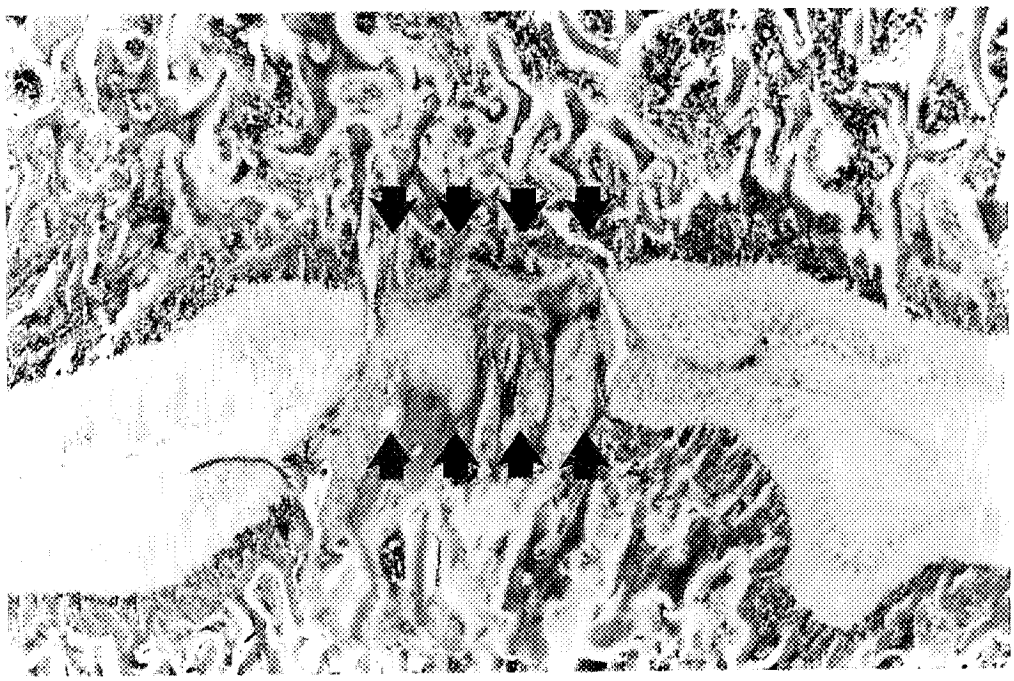

FIG. 5

Photomicrograph demonstrating another osseous bar (arrows) across the ilioischial limb (hematoxylin and eosin, × 2.5).

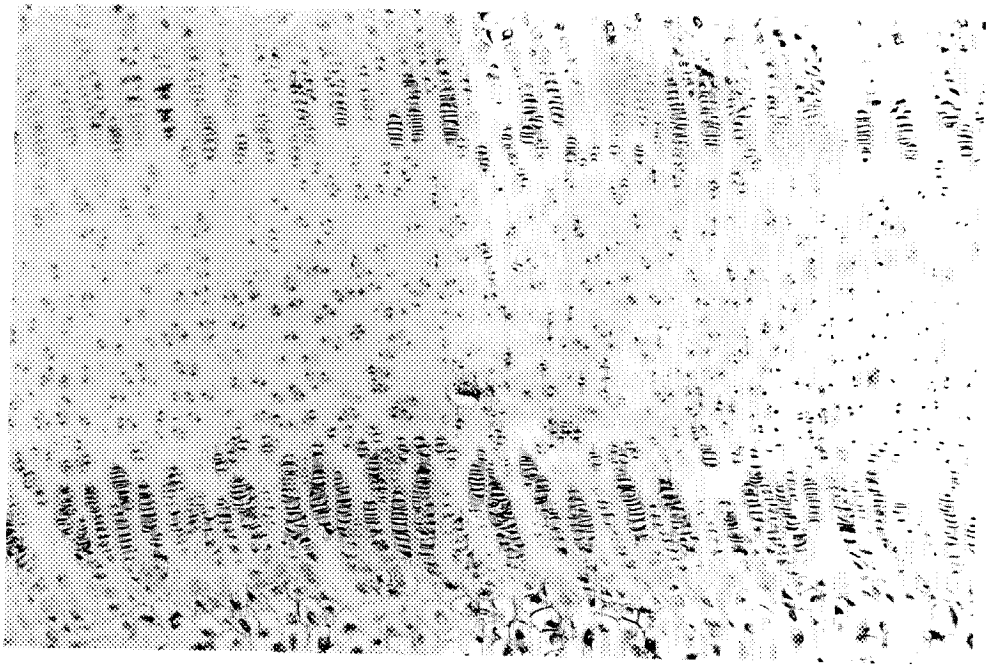

FIG. 6-A

Photomicrograph of the ilioischial limb of normal triradiate cartilage (hematoxylin and eosin, × 200).

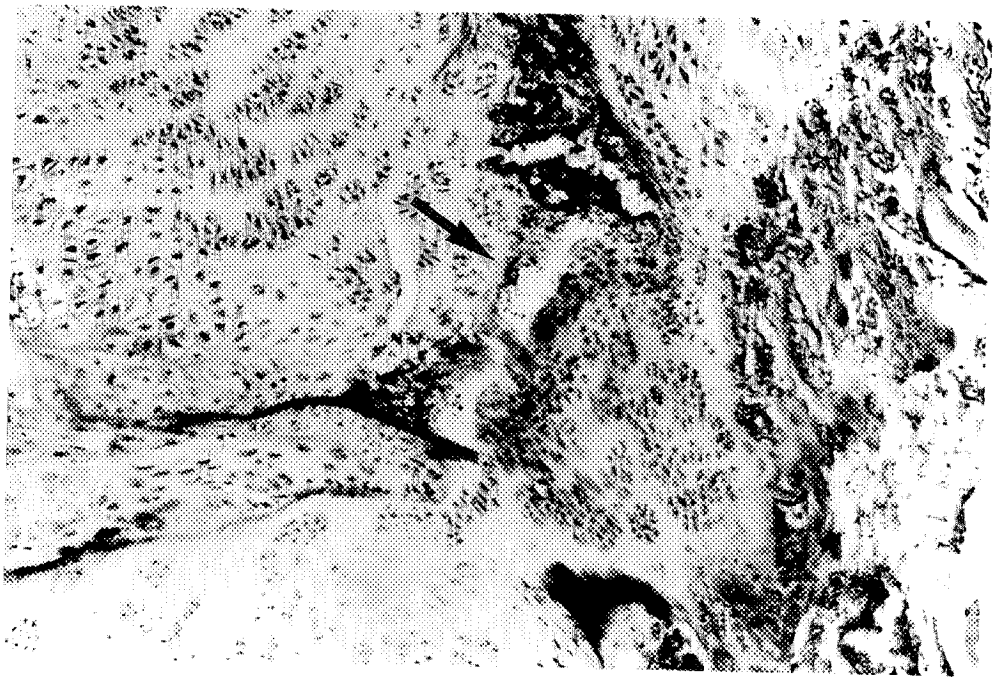

FIG. 6-B

Photomicrograph showing disruption of the ilioischial limb of the triradiate cartilage (arrow) after a Pemberton osteotomy (hematoxylin and eosin, × 200).

diate cartilage. The periosteum over the physis was not disturbed, but its location allowed an estimate of the depth of the osteotomy. The osteotomy was performed with both curved and straight one-quarter-inch (6.4-millimeter) osteotomes. Bone from the iliac crest was placed in the osteotomy site. The wound was irrigated and closed. Malignant hyperthermia developed intraoperatively in one animal and was treated successfully with dantrolene sodium and cooling blankets. There were no other intraoperative complications. Anteroposterior radiographs of the pelvis were made postoperatively with the piglet under anesthesia and were used to evaluate the site of the osteotomy.

To simplify care, no postoperative immobilization was used. For approximately two days after the operation, the four animals that had had a unilateral osteotomy flexed the involved knee and used a three-limb gait to avoid walking on the treated hindlimb. After two days, the animals walked normally about the pens. The two animals that had had a bilateral osteotomy lay down for a few days and then started walking on all limbs.

The two animals that had had a bilateral Pemberton osteotomy were killed by lethal injection two weeks postoperatively. The four acetabula were procured and were studied only histologically.

The four animals that had had a unilateral Pemberton osteotomy were killed two months postoperatively. The eight acetabula (four that had been treated and four that were used as controls) were removed and were fixed in 10 percent formalin. The specimens were placed on a radiographic cassette to simulate an anteroposterior radiograph of the pelvis. A Bucholz radiograph was then made with the acetabulum face down on the cassette to show the entire triradiate cartilage[1]. Next, the specimens were placed in a computed tomography scanner, and images were made with a one-millimeter slice thickness throughout the entire specimen. The images were used to make a three-dimensional reconstruction of the specimen. With these reconstructed images, the specimens could be rotated so that the orientation of the cuts could be manipulated to produce computed tomography scans that matched the orientation of the histological sections.

The specimens were decalcified in 5 percent buffered formic acid, washed, and embedded in paraffin. They were then halved with a cut made parallel to the acetabulum (Fig. 1), cut at sixty-micrometer intervals both anterior and posterior to the initial cut, and stained with hematoxylin and eosin. The histological sections were then examined for evidence of osseous bars. The width of the bars was measured with an eyepiece reticle.

Results

Preoperative anteroposterior radiographs of the pelvis revealed minimum dysplastic changes as a result of the binding of the lower extremity. The Pemberton osteotomies were performed easily despite the fact that the acetabula were less capacious than anticipated. Postoperative radiographs (Fig. 2) showed that the Pemberton osteotomy had increased acetabular coverage compared with that seen on the preoperative radiographs. There was no radiographic or histological evidence that any bone graft had been inadvertently placed across the triradiate cartilage.

Histological study of the four acetabula from the two pigs that had been killed two weeks after a bilateral osteotomy demonstrated an osseous bar in one specimen and bars in both the iliopubic and the ilioischial limb of the triradiate cartilage in another (Table I and Figs. 3, 4, and 5). The latter specimen had two osseous bars across the disrupted ilioischial limb (Fig. 5). The bars in the two specimens ranged from 0.04 to two millimeters wide.

Of the remaining two specimens that were studied two weeks postoperatively, one had areas of disruption of the triradiate growth plate without osseous bridging. In these areas, the otherwise orderly cellular pattern of the growth plate was disrupted (Figs. 6-A and 6-B) and fragments of cartilage were separated from the physis (Fig. 7). Fibrotic tissue or marrow was sometimes seen in the disrupted areas. The ilioischial and iliopubic limbs on each slide were compared with the ischiopubic limb, which was used as an internal control because it does not serve as the hinge in the Pemberton osteotomy. As expected, there were no disruptions of the growth plate in the ischiopubic limb.

The specimens from the four piglets that had been killed two months after a unilateral Pemberton osteotomy were placed laterally on radiographic cassettes, with the iliopubic and ilioischial limbs of the triradiate cartilage superimposed as they are on an anteroposterior radiograph of the pelvis of a human (Fig. 8). In three specimens, the superimposition of the two limbs was imperfect, and several radiographs were slightly oblique, with the iliopubic and ilioischial limbs seen more distinctly as two limbs rather than as one superimposed structure. Osseous bars were clearly seen in only

FIG. 7

Photomicrograph showing disruption of the triradiate cartilage, with cartilage fragmented from the physis. The wide straight arrows indicate cartilaginous islands, and the thin curved arrows indicate the disrupted region of the physis (hematoxylin and eosin, × 2.5).

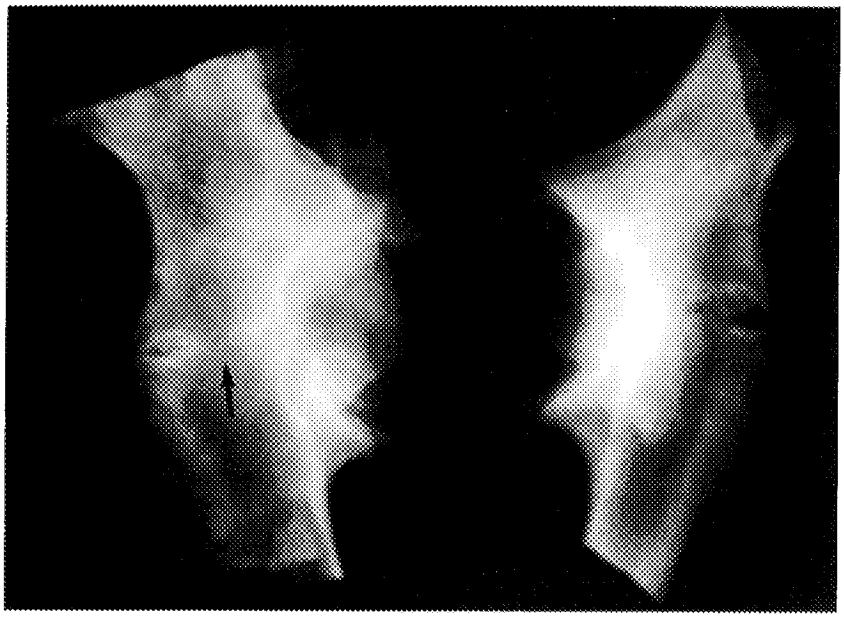

FIG. 8

Anteroposterior radiograph of a specimen oriented with the iliopubic and ilioischial limbs of the triradiate cartilage superimposed, as they are on an anteroposterior radiograph of the pelvis of a human. An osseous bar (arrow) formed in the specimen on the left following a Pemberton osteotomy. The specimen on the right is the control.

one specimen. Turning the acetabulum face down on the cassette for the Bucholz radiograph allowed radiographic visualization of osseous bars in three specimens (Fig. 9). These three specimens were noted histologically to have osseous bars; thus, the Bucholz radiograph was more sensitive to injury of the triradiate cartilage than the simulated anteroposterior radiograph of the pelvis was. Unfortunately, it is not possible to make a Bucholz radiograph of a living human being.

Computed tomography scanning of the specimens was followed by three-dimensional reconstruction to allow symmetrical rotation of the control and study specimens (Figs. 10-A and 10-B). Cuts were made along the reconstructed pelvis perpendicular to the ilioischial and iliopubic limbs in the manner in which they were made in the histological sections (Fig. 1). Computed tomography scanning confirmed the osseous bars that had been seen in the histological specimens, but the bars were difficult to find with only the computed tomography scans because of the small size of the pig pelvis.

The histological studies of the four healed oste-

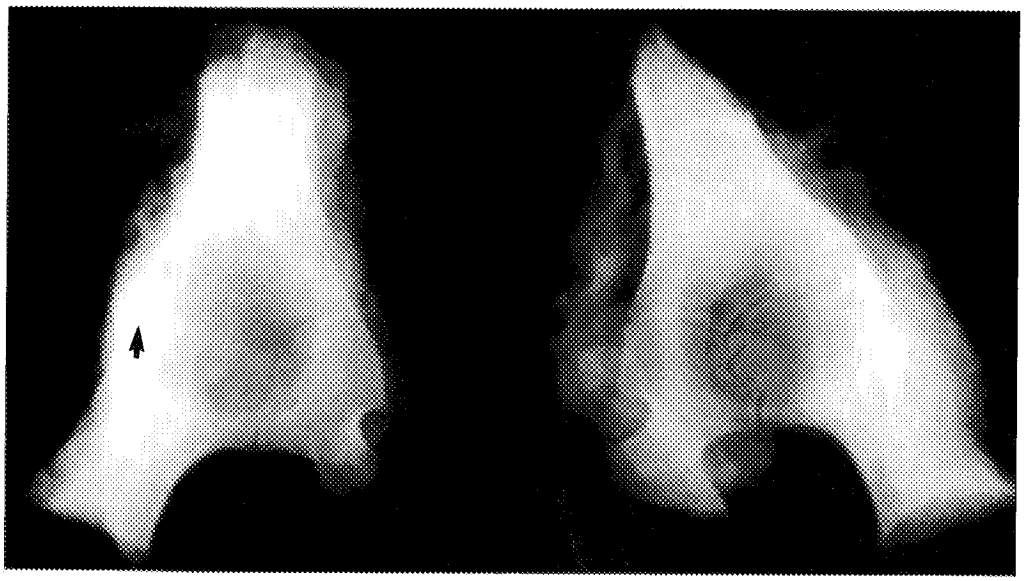

FIG. 9

Bucholz radiograph of the same specimen shown in Fig. 8. An osseous bar (arrow) formed in the specimen from the treated hip (left). The specimen on the right is the control.

otomy sites that were examined two months postoperatively demonstrated woven bone along the sites. Five osseous bars were identified in three of the four specimens. Two specimens had a bar in both the iliopubic and the ilioischial limb, and one specimen had a bar in only the iliopubic limb (Table I). The bars were 0.64, 0.76, 0.88, 1.3, and 1.4 millimeters wide as measured in the section that showed the largest diameter of the bar. Unlike the specimens that were examined at two weeks, no specimen had disruption of a limb without the formation of an osseous bar. One specimen had no evidence of injury of the triradiate cartilage following the Pemberton osteotomy.

TABLE I

HISTOLOGICAL RESULTS

Specimen	Ilioischial Limb	Iliopubic Limb
Two wks. postop.		
1	Normal	Normal
2	Disrupted	Bar
3	Bar (two)	Bar
4	Disrupted	Normal
Two mos. postop.		
5	Normal	Normal
6	Bar	Bar
7	Normal	Bar
8	Bar	Bar

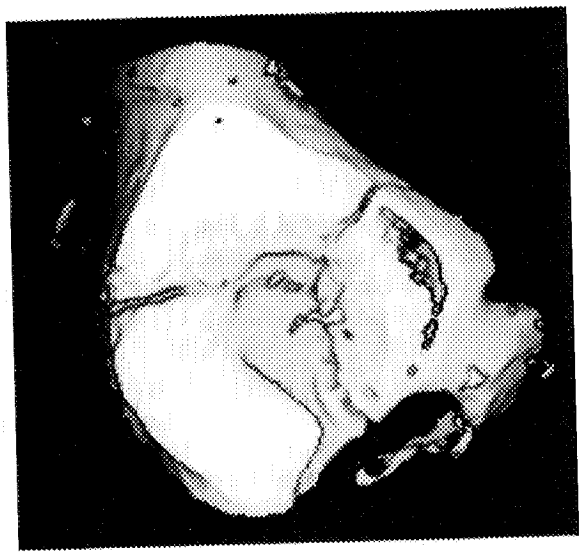

FIG. 10-A

FIG. 10-B

Three-dimensional computed tomography reconstructions of the control side (Fig. 10-A) and the treated side (Fig. 10-B) from the same animal. The arrows on the image of the treated side indicate osseous bars in the ilioischial and iliopubic limbs, which were also seen in the histological specimens.

Discussion

The formation of osseous bars in the iliopubic or ilioischial limb of the triradiate cartilage of the pigs in the present study suggests that Pemberton osteotomy may lead to acetabular dysplasia. Osseous bars were evident in five of the eight specimens. The formation of such bars may not be apparent on plain radiographs of the pelvis. We do not know whether these bars, which ranged in width from 0.04 to two millimeters, are large enough to cause acetabular growth disturbance. The osseous bars formed in both the ilioischial and the iliopubic limb. Previous studies of animals have demonstrated that bars that form in the iliopubic limb may not be as serious as those that form in the ilioischial limb[3]. It is difficult to extrapolate, from our pig model, the width of bars that would be produced in humans following Pemberton osteotomy or whether subsequent acetabular changes would occur.

We believe that the disruption of the physis occurs as the osteotome crosses the growth plate. The growth plate could be damaged further as a result of pressure and crush induced when the acetabulum is hinged on the triradiate cartilage and bone graft is impacted into the site of the osteotomy. At our institution, Pemberton osteotomies are performed with use of image intensification and the osteotome is placed to within five millimeters of the growth plate, with the soft cancellous bone serving as the hinge of rotation. Adequate coverage of the femoral head can be obtained with this technique. In addition, this modification may avoid damage of the triradiate cartilage.

Two of the specimens obtained two weeks postoperatively had disruption of the growth plate without the formation of an osseous bar in the same limb. There was no such disruption in the absence of an osseous bar in the specimens studied at two months postoperatively; either an osseous bar developed or the growth plate was normal.

The characteristics of injury of the growth plate in a

pig may be comparable with those in a child. If an osteotome passing near or through the growth plate in a pig damages the triradiate cartilage, then a child with acetabular dysplasia who has an osteotomy may be at risk for injury of the triradiate cartilage.

Computed tomography scans of the pelvis may be useful to reveal osseous bars in the triradiate cartilage following Pemberton osteotomy. We believe that the radiation associated with such scans is justified by the results of this study; such scans are necessary to ensure that the operative intervention designed to improve the acetabular contour does not disrupt acetabular growth and lead to loss of acetabular correction.

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